PACS data reduction for the PEP deep extragalactic survey

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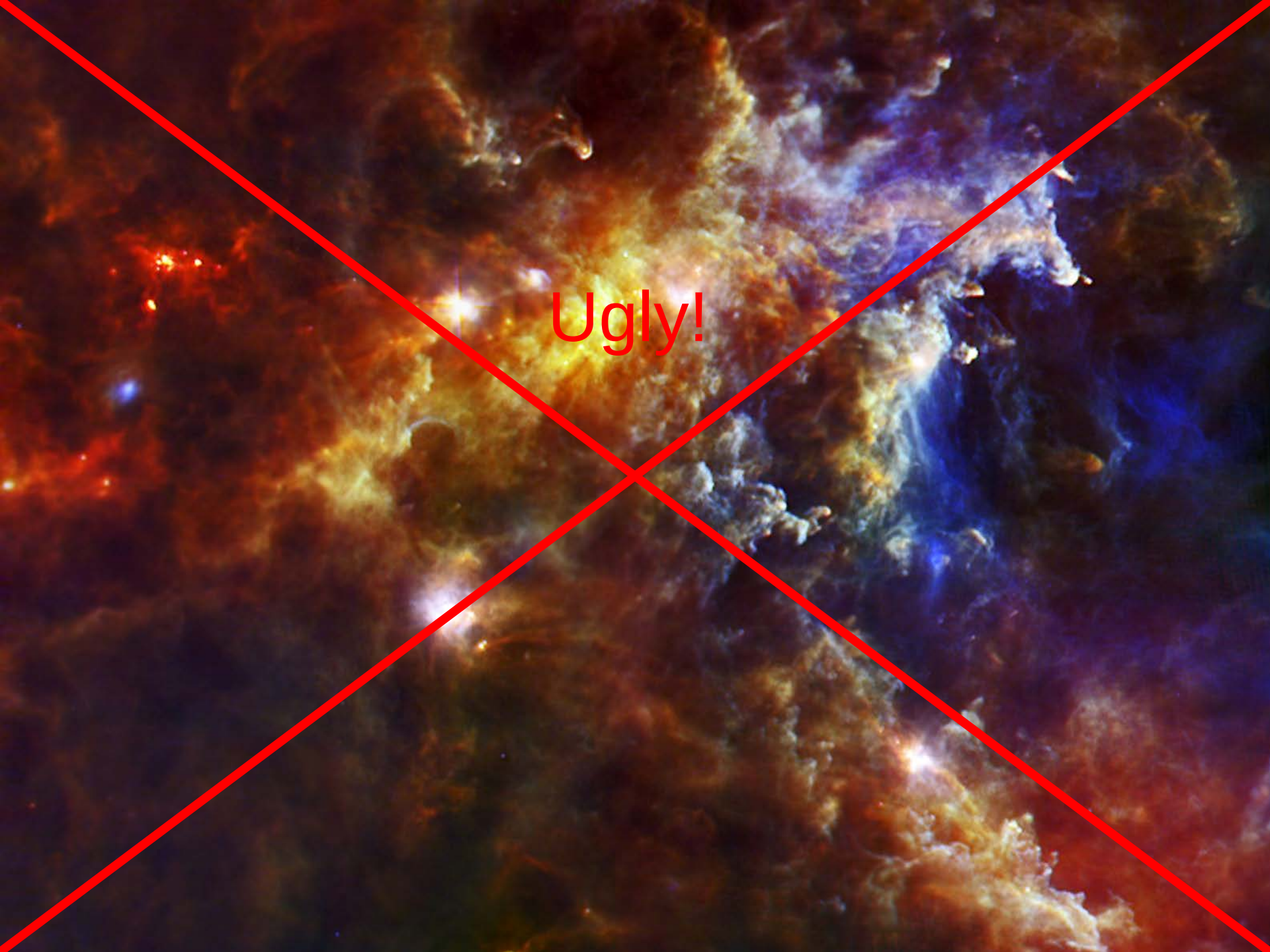
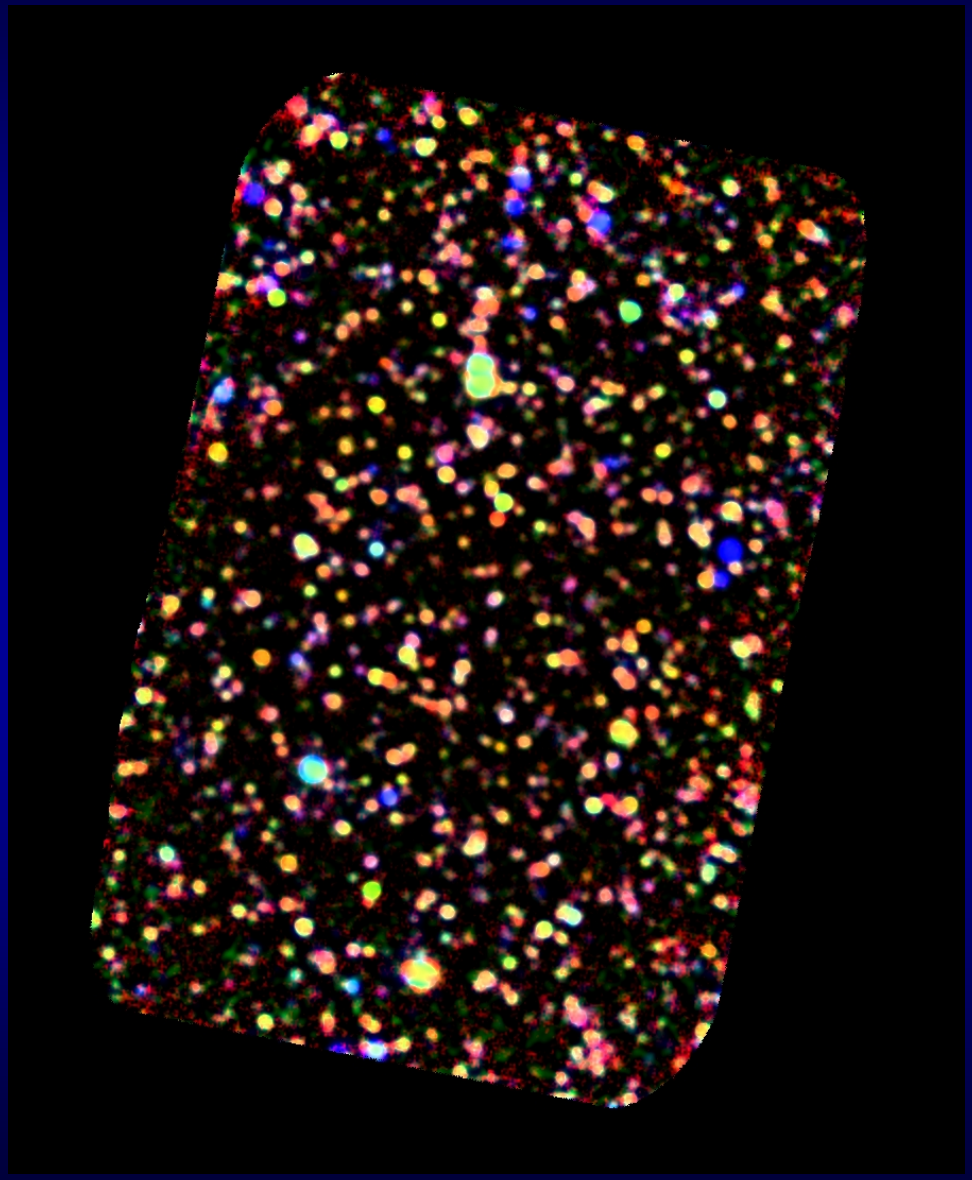
and the PEP reduction team

Herschel map making workshop Jan 28-31 2013


Ugly!


Boring!

Beautiful!



… how do we detect yet more of these point sources …

Field	ations	Time hours
COSMOS	Jun 2010	196.9
Lockman Hole XM	Nov 2009	32.1
EGS	June 2011	34.8
ECDFS	Feb 2011	32.8
GOODS-S	010	239.7
GOODS-N	009	25.8
Cl0024+16	010	6.2
Abell 370		5.3
MS0451.6-0305	010	5.3
Abell 1689	11 –	13.0
RXJ1347.5-1145	011	5.3
MS1358.4+6245	010	5.3
Abell 1835	011	5.3
Abell 2218	009	10.2
Abell 2219	010	5.3
Abell 2390	010	5.3
RXJ0152.7-1357	Jan 2011	5.8
MS1054.4-0321	Dec 2010	5.8

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Basic considerations

- Point source sensitivity
- PSF sharpness
  - Raw sensitivity, deblending, confusion noise

- No need to preserve extended emission

➢ Stick with standard masked highpass filtering
  - Basic steps not repeated here – ipipe script, see also Bruno Altieri's presentation

Similar methods used by the GOODS-Herschel and HLS deep PACS surveys

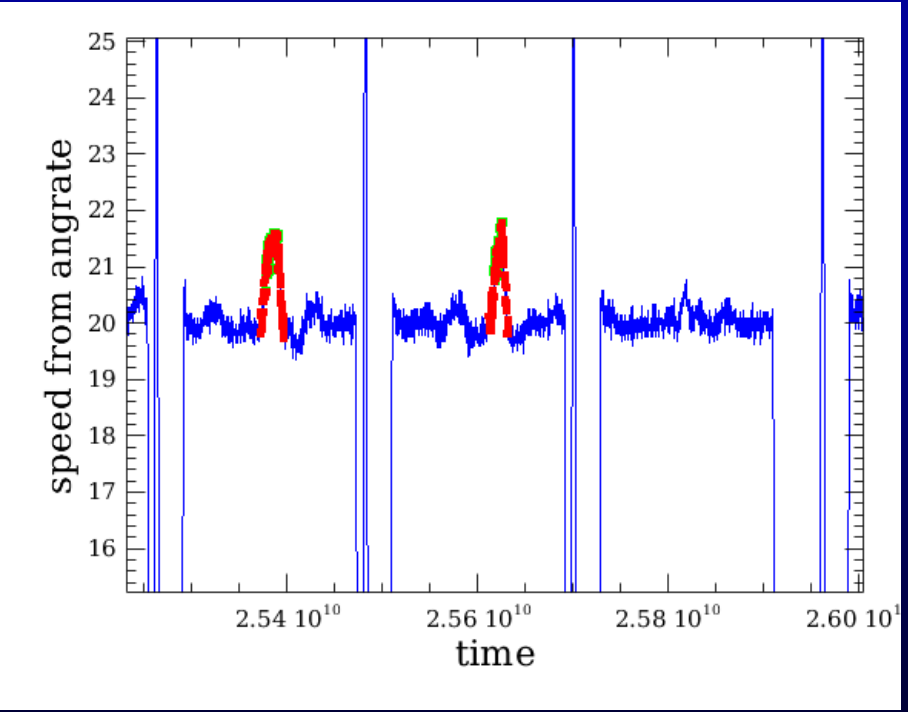
Not covered in this talk: Blind & prior source extraction

Editing: Eliminating ‘speed bumps’

- Guide star crosses an ill-behaving (but unflagged) star tracker pixel
- Pointing system reacts, to stay on what it thinks is a straight scanleg
  - Scanleg reported in pointing product *positions* is straight
  - True path on sky deviates in an unknown way
- A signature is left in the gyro velocity signal, though – this leaves an imprint in the pointing product angular velocities.

- Use script finding speedbumps on medium speed data, and discard affected data.

- Gone OD320+ (lower STR temperature)

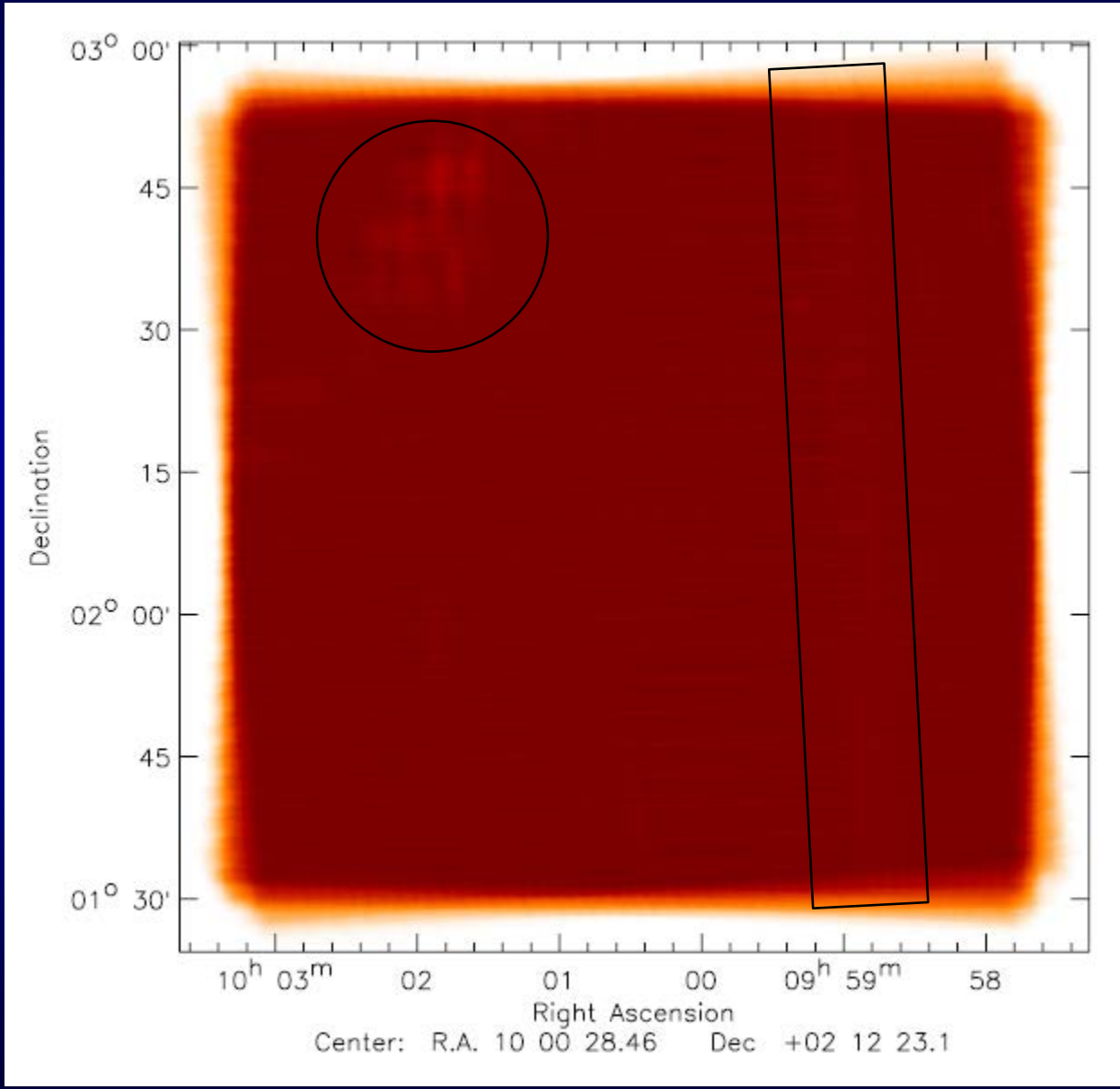


Editing: Eliminating severely fringed ‘blue’ data

- Blue/green channel PACS data occasionally show fringes due to stray magnetic fields from spacecraft
- Create a separate scanmap jpg from each and every scanleg
- Inspect visually to identify severly fringed data
  - The eye is fast….
- Discard severely affected scanlegs

- Little effect on coverage due to large redundancy in PEP fields
- Keeping them would likely have minor effect on S/N (though not rigorously quantified)

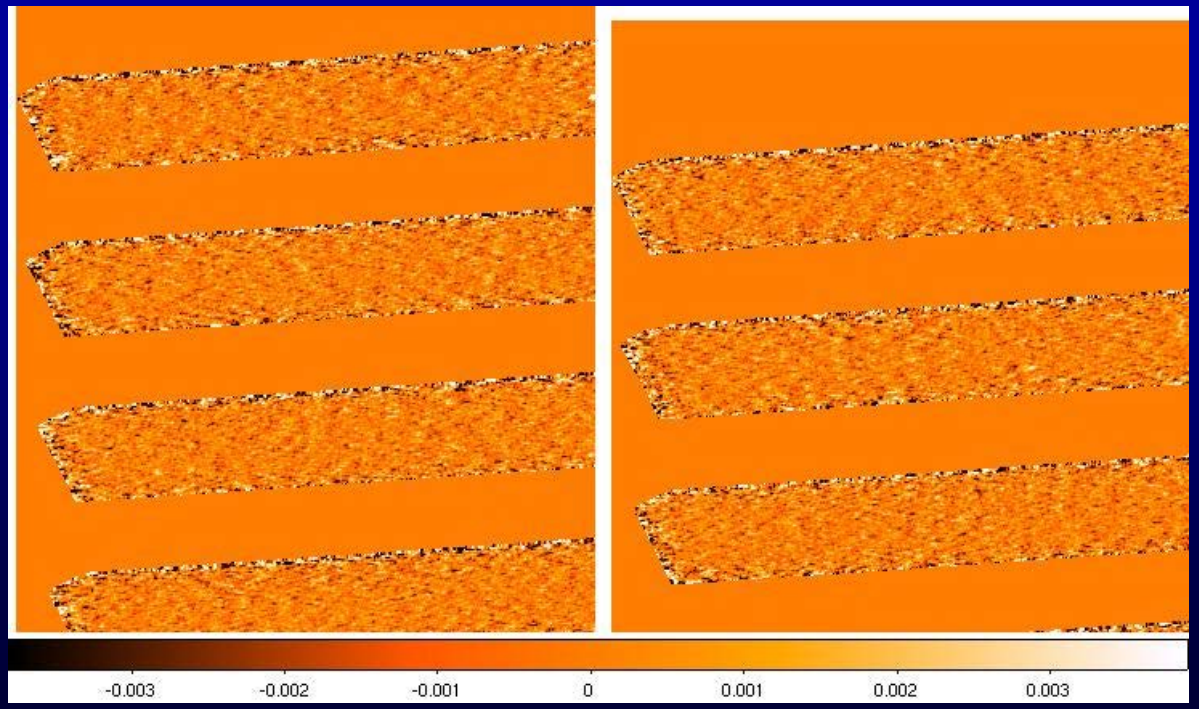
Example coverage after editing



Recentering on astrometric reference

- Uncorrected PEP maps are astrometrically off by (globally) up to 5arcsec
- Possibility of timing issues satellite vs. PACS data
- Possibility of pointing offset drifts

- Create maps from **typically ~15minutes** of data, one scan direction only
- Stack into position of deep 24micron catalogs with good astrometry (radio catalogs are a viable alternative) to derive pointing correction
- Reprocess, fudging the pointing of these subsets with applicable offsets



Choice of high pass filter

- Significant 1/f noise in PACS bolometers suggests to go ‘as small as possible’, but beware of effect on fluxes for both masked and unmasked point sources

- NEED SIMULATIONS

- Quick 2009 simulations using real ILT noise timelines with an artificial sky:
  - HPF radius 15 samples (blue & green, medium speed) and 26 samples (red, medium speed) should be safe
- Now adopted for our case, on the basis of better simulations:
  - HPF radius 12 samples (blue & green, medium scanspeed) and 20 samples (red, medium scanspeed)

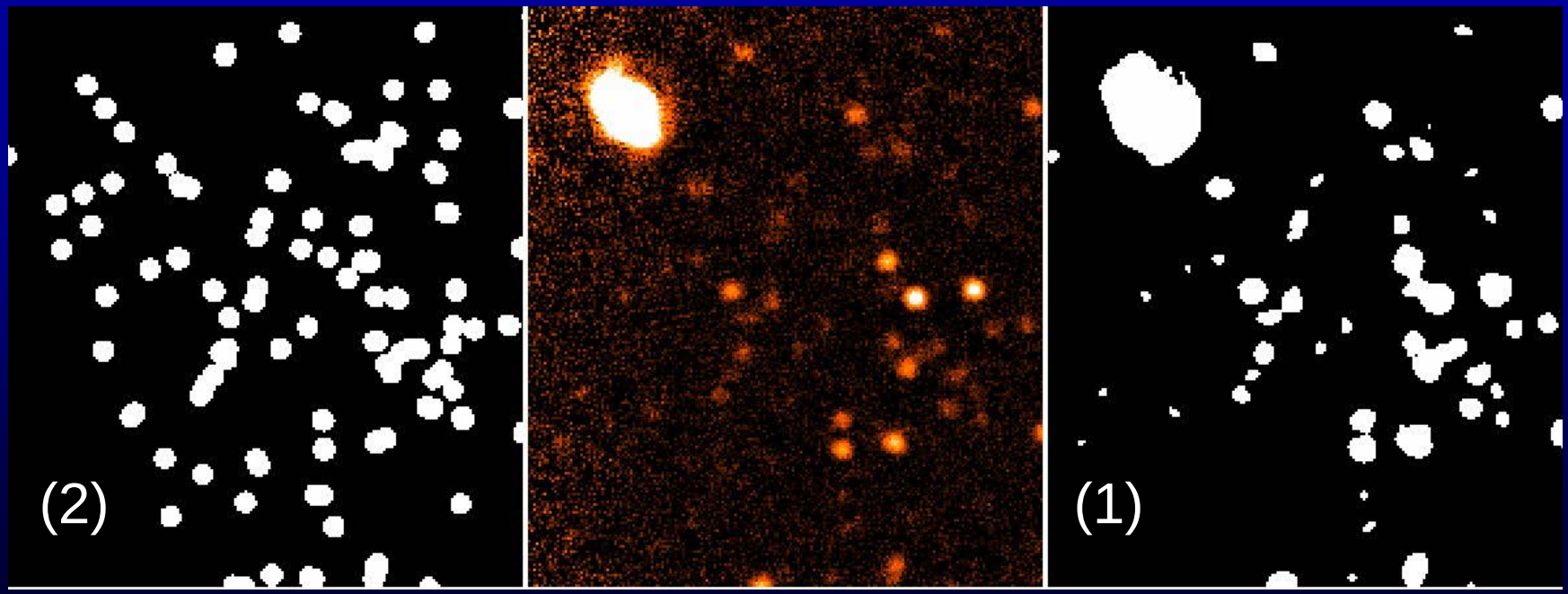
- Of course, such parameters will be **bad** for extended sources……

Choice of masking strategy

- Option 1: Derive a first science map, smooth, set a S/N based threshold
- Option 2: Place circular mask patches (~PSF size) at the positions of sources, from a first reduction or from an external catalog strongly correlated with PACS (24micron!)

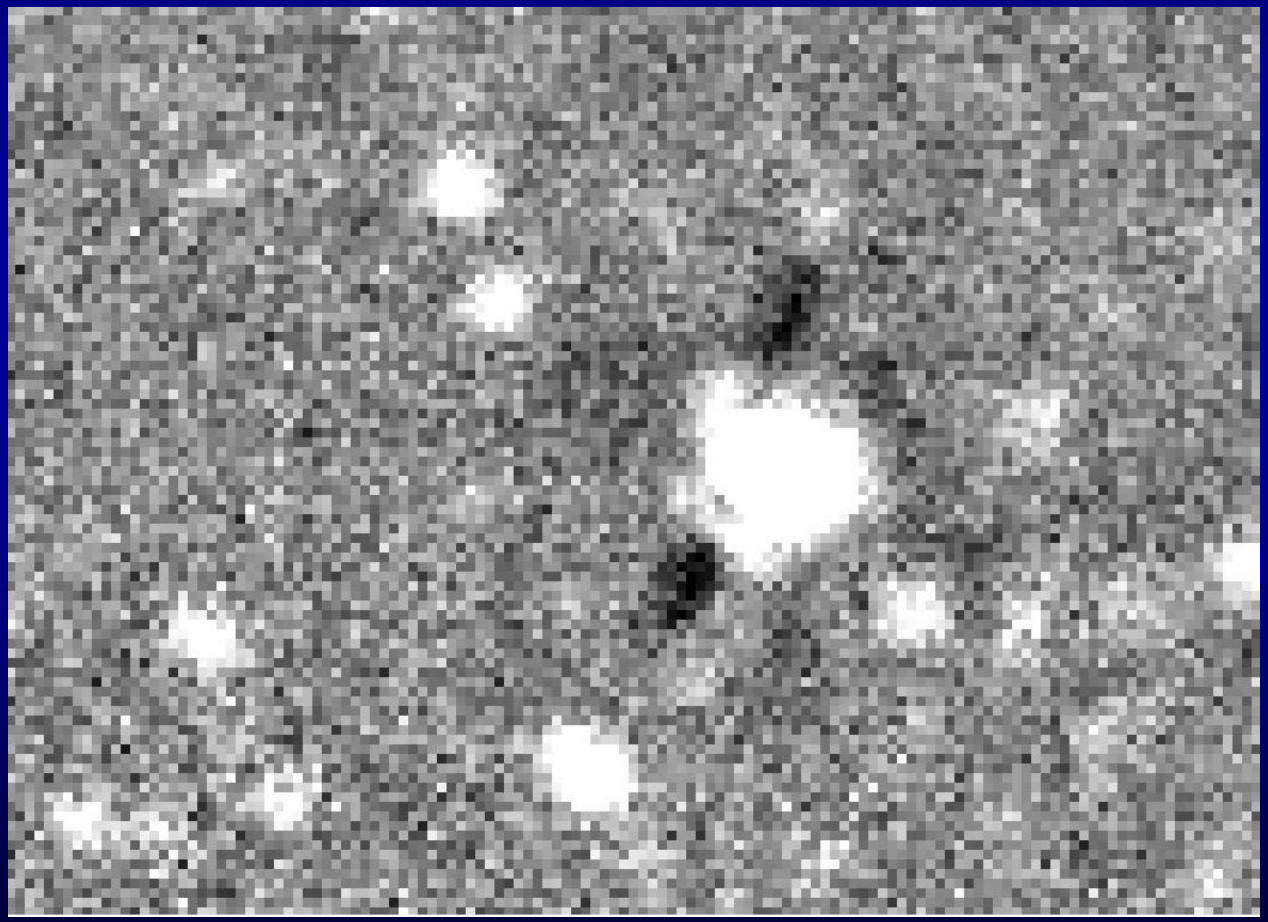
- Both options will still cause flux losses by HPF, that need to be quantified

- PEP switched from (1) to (2')

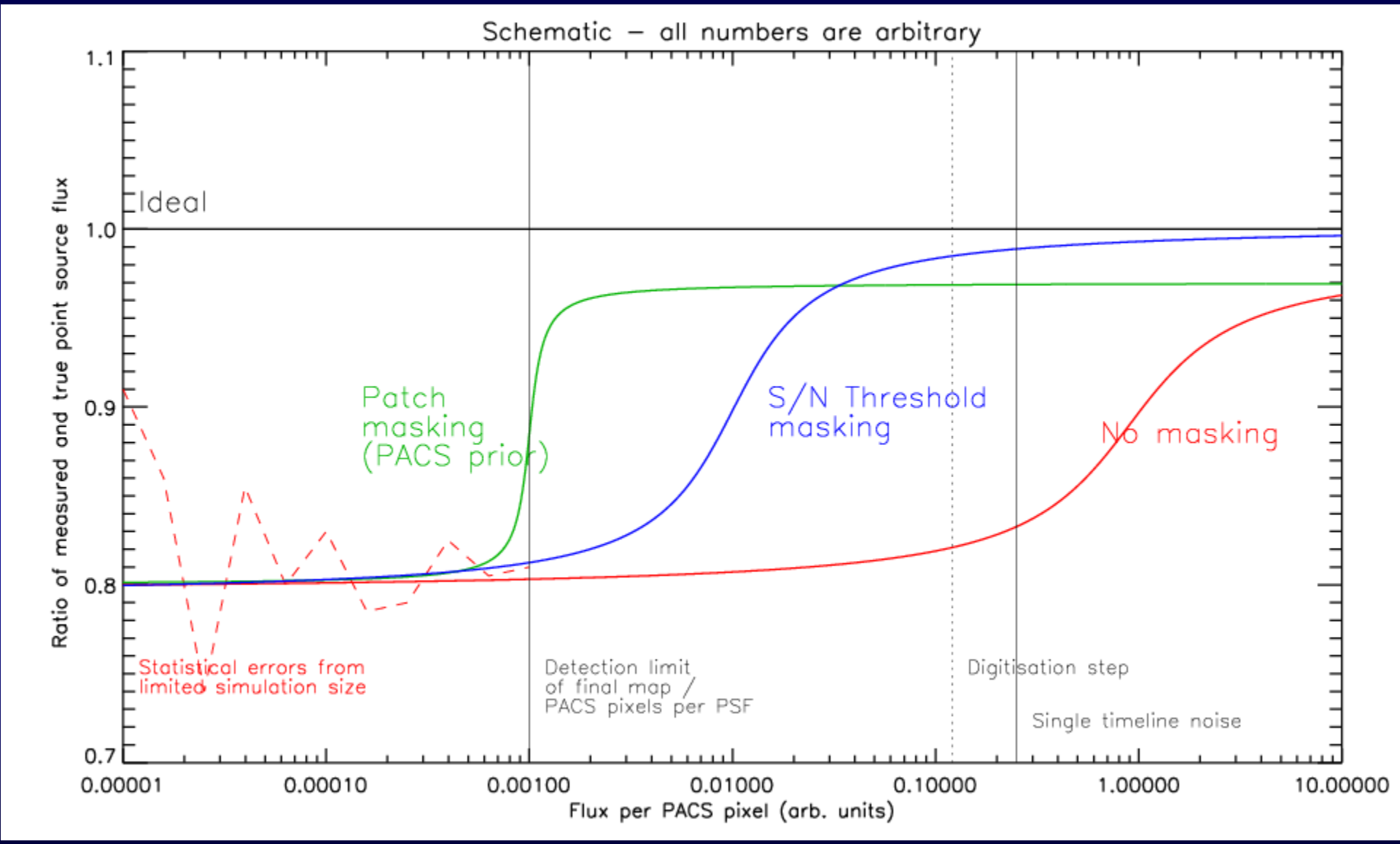


Check your maps and masks…

- Patch masking can leave HPF residues near few very bright sources (even more if they are slightly extended)
- Extend patch size around such sources (radius or S/N-based)



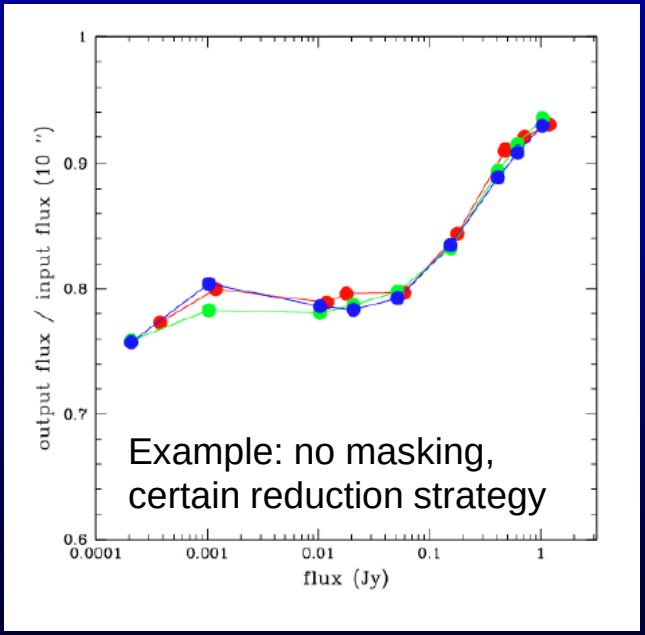
Schematic effect of S/N based and patch masking on point source flux



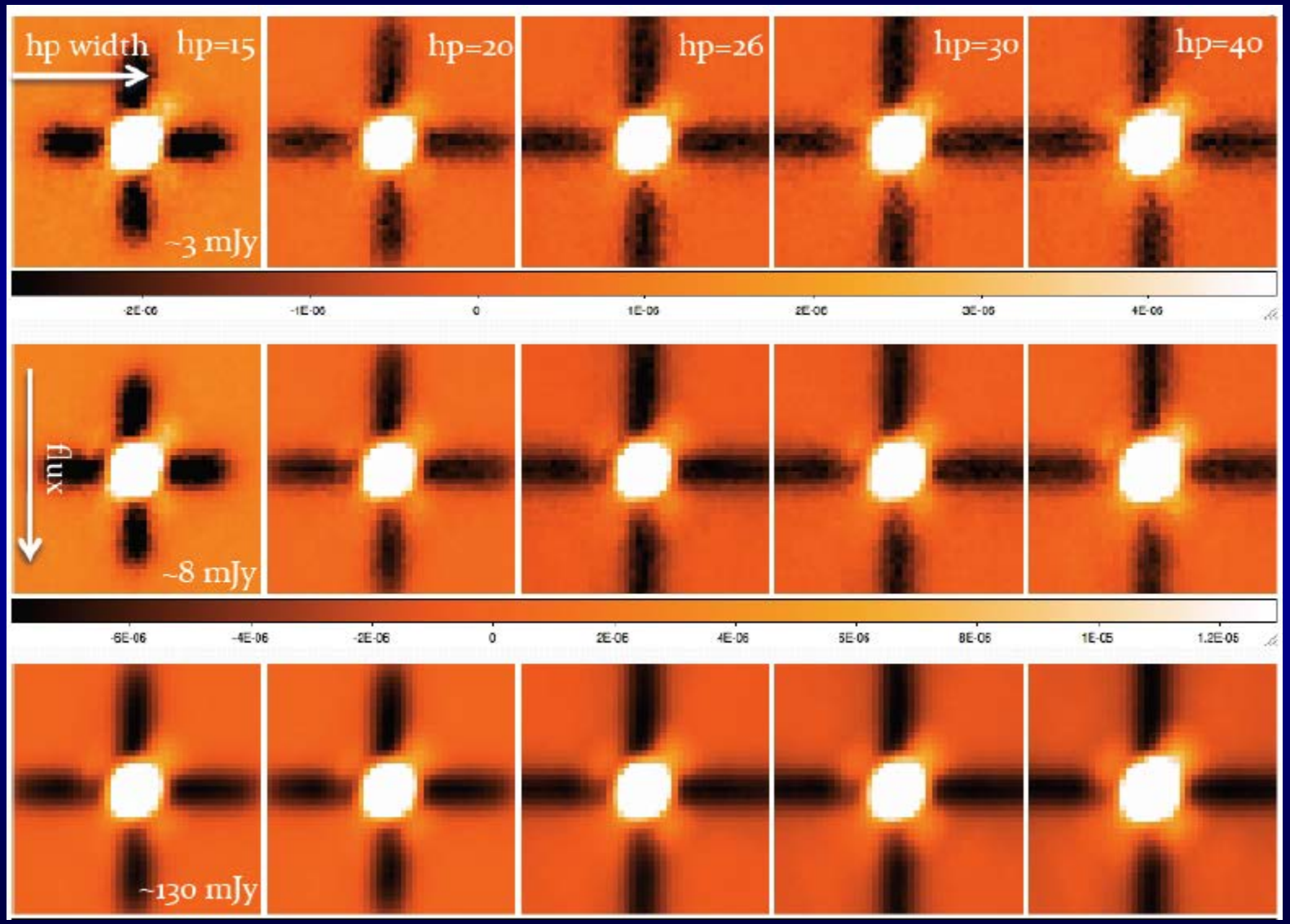
Simulations of HPF effects

- Use real deep field observations as basis: Real noise, background sources fully realistic
- Project additional artificial sources into individual timelines, before masking and high pass filtering
- PEP used an IDL backprojection, but HIPE now provides map2signalCubeTask for this purpose
- Process original data and data with artificial sources in the same way (masking strategy, HPF). Use difference maps to quantify distortion/flux loss of artificial sources

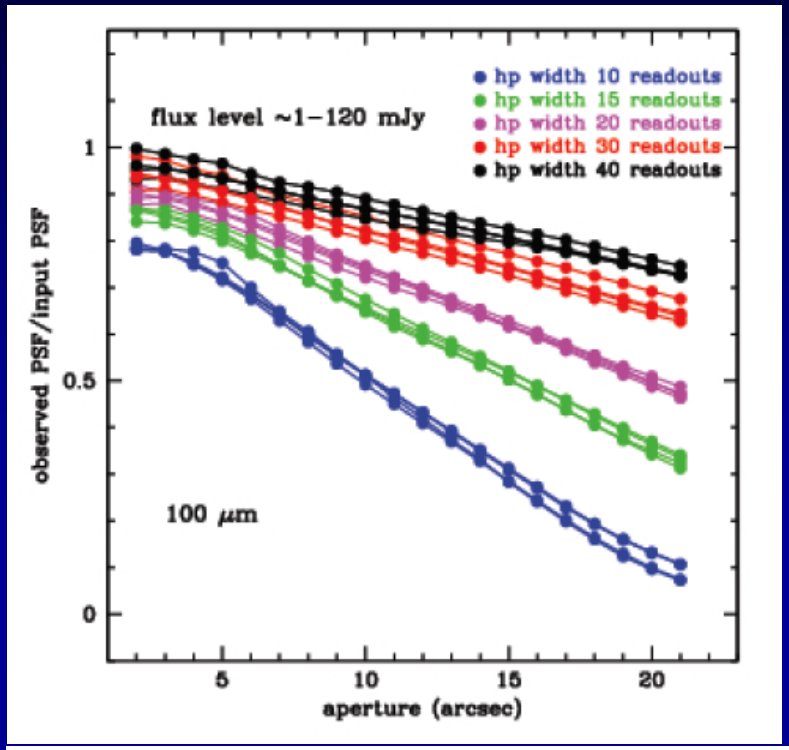
- Popesso et al. 1211.4257 present extensive results for various reduction parameters and patch masking strategy



Simulation results (difference maps with/out artificial sources)

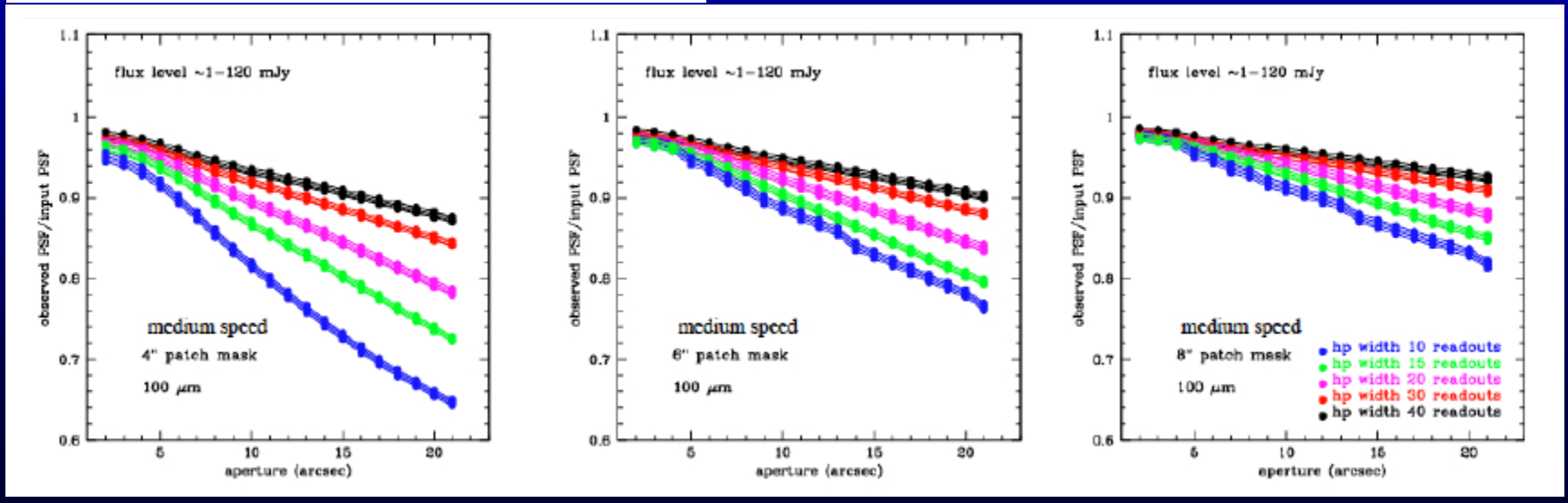


Simulation results



No masking

Different sized patch masks



Pixel and drop size

- Smaller pixel sizes improve PSF width
- Smaller drop sizes reduce noise correlation (and improve PSF width)
- PEP data are highly redundant

Parameters adopted in final reductions:

- Green, Blue: Pixel size 1.2arcsec, pixfrac 0.06
- Red: Pixel size 2.4arcsec, pixfrac 0.06

Weighted projection

- There are modest variations of noise/flatfield over the PACS arrays
- photProject is able to consider errors and do a weighted projection
- No reliable error propagation in the upstream pipeline

➢ Since PEP individual timelines are almost source free, measure noise in the individual timelines just before projection, and insert into the frames noise cube

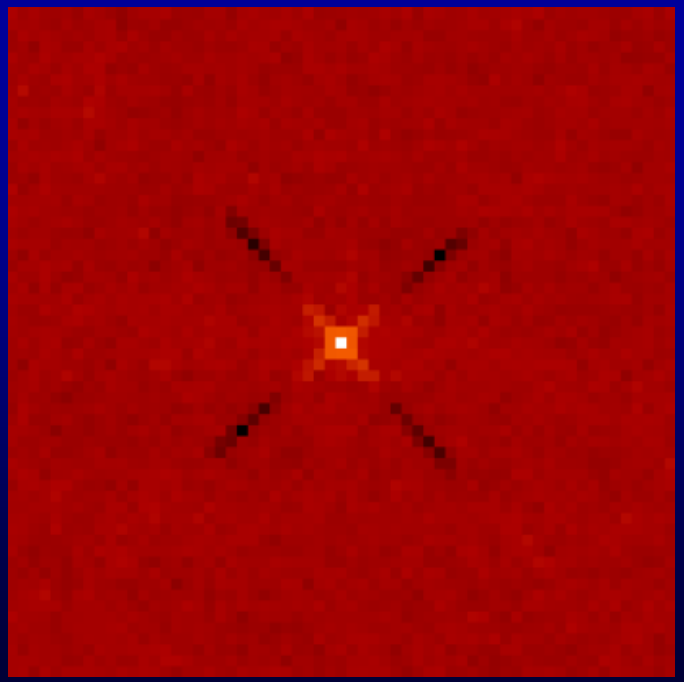
➢ Minor effect on overall noise (but in the right direction)

Estimating noise and correlated noise

- PEP total maps are coadds from many AORs/scan repetitions
- Error map for total map can be derived directly from dispersion in contributing maps (considering coverage of each map, and number of maps)
- There is noticeable correlation between noise in neighbouring pixels due to
  - Projection effects (reduced by small drop size)
  - Residual 1/f noise in filtered timelines
- Build a noise correlation map from comparing many pixel pairs
- Derive correction factor for noise correlation from correlation map and PSF used for extraction

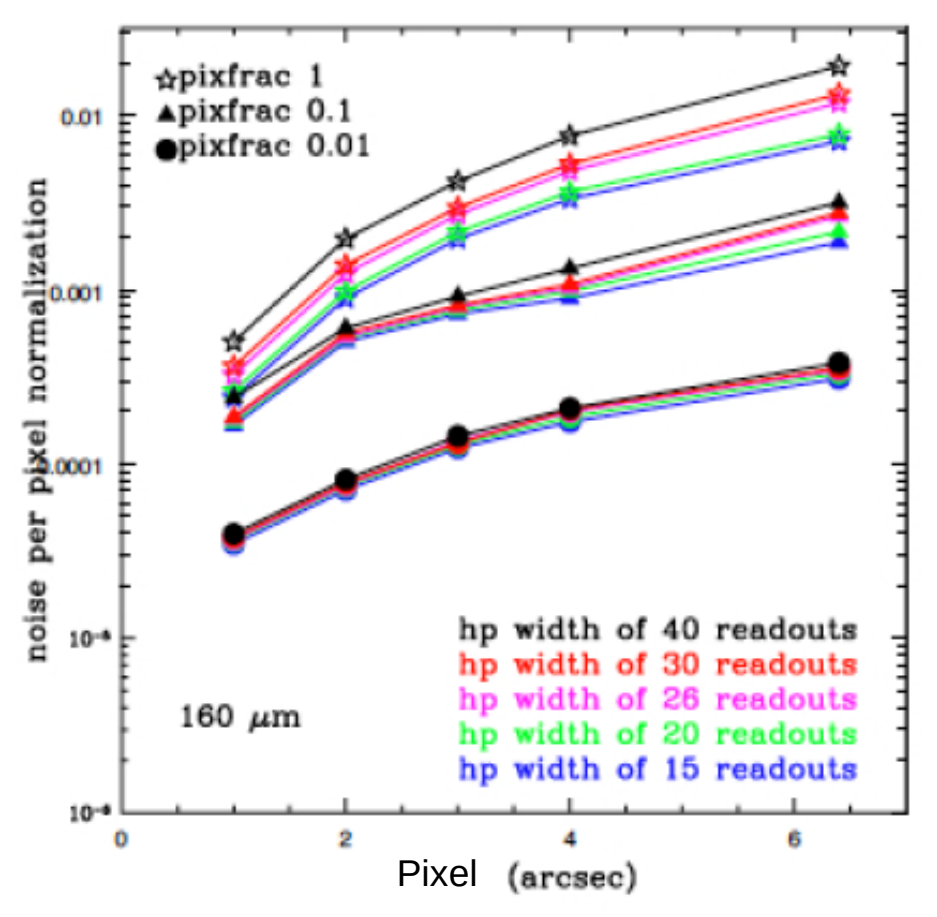
$$f^2 = \frac{\sum_k P_k^2}{\sum_{i,j} P_i P_j \rho(i,j)}.$$

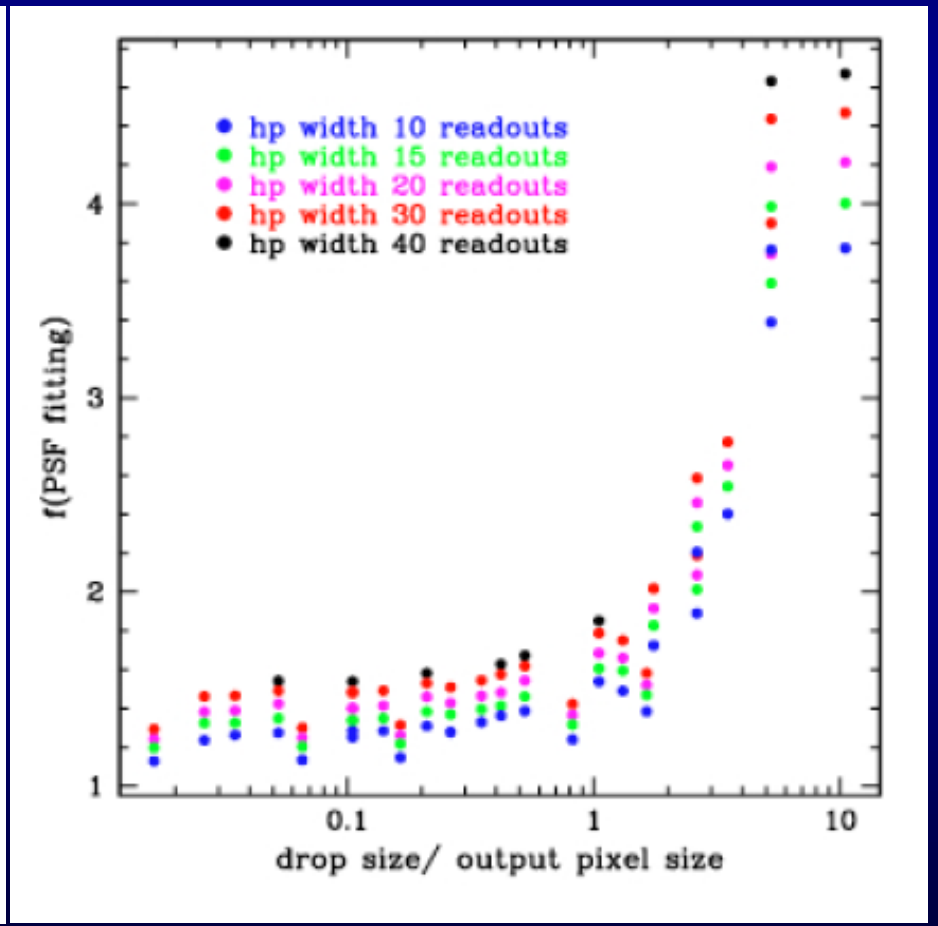
- Typically f~1.5 for our parameters



What if your data are less redundant?

Popesso et al. 1211.4257 (Section 8) exercise these methods over a wide parameter space and derive suitable scaling relations for the noise/coverage ratio and for the correlation correction, given PACS band and reduction parameters (HIPE: photCoverage2Noise)



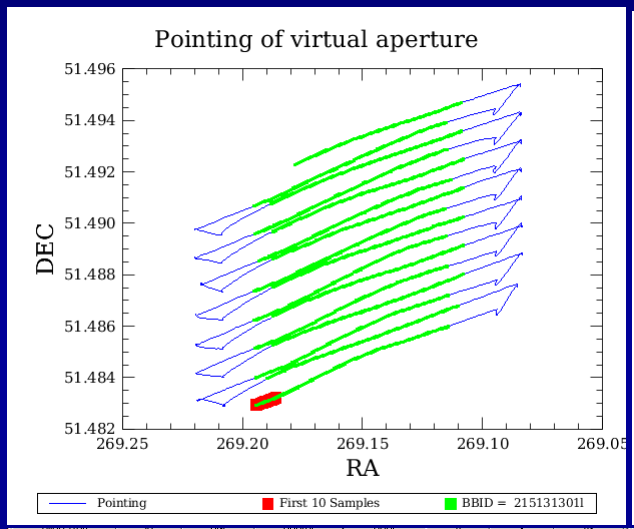


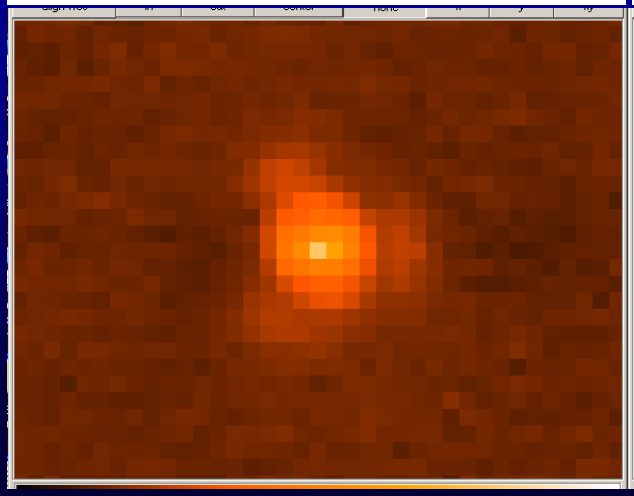
Possible improvements: Gyro-reconstructed pointing

- See Herve Aussel's presentation!

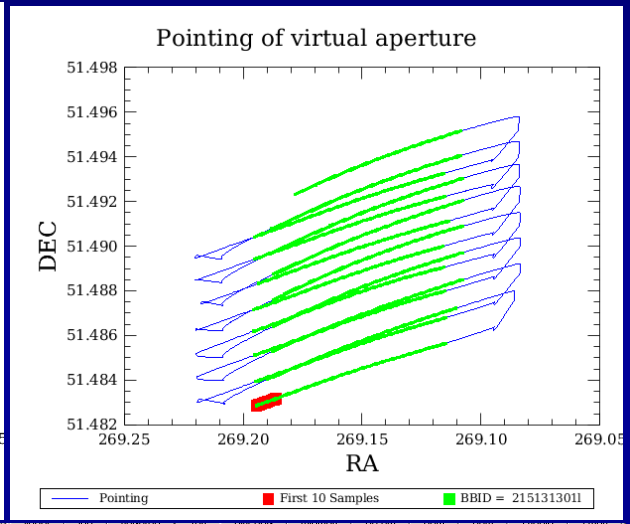
Example observation with BAD pointing

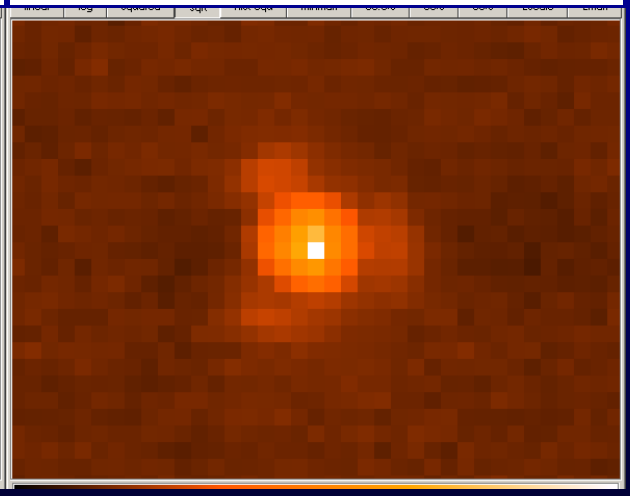
Before (old PP)





After (gyro-reconstructed)





Peak height: 37 → 64 arb. unit
FWHM: 1.66 → 1.36 arb. unit

Typical observations will have more subtle improvements!

Possible improvements: FOV Distortion

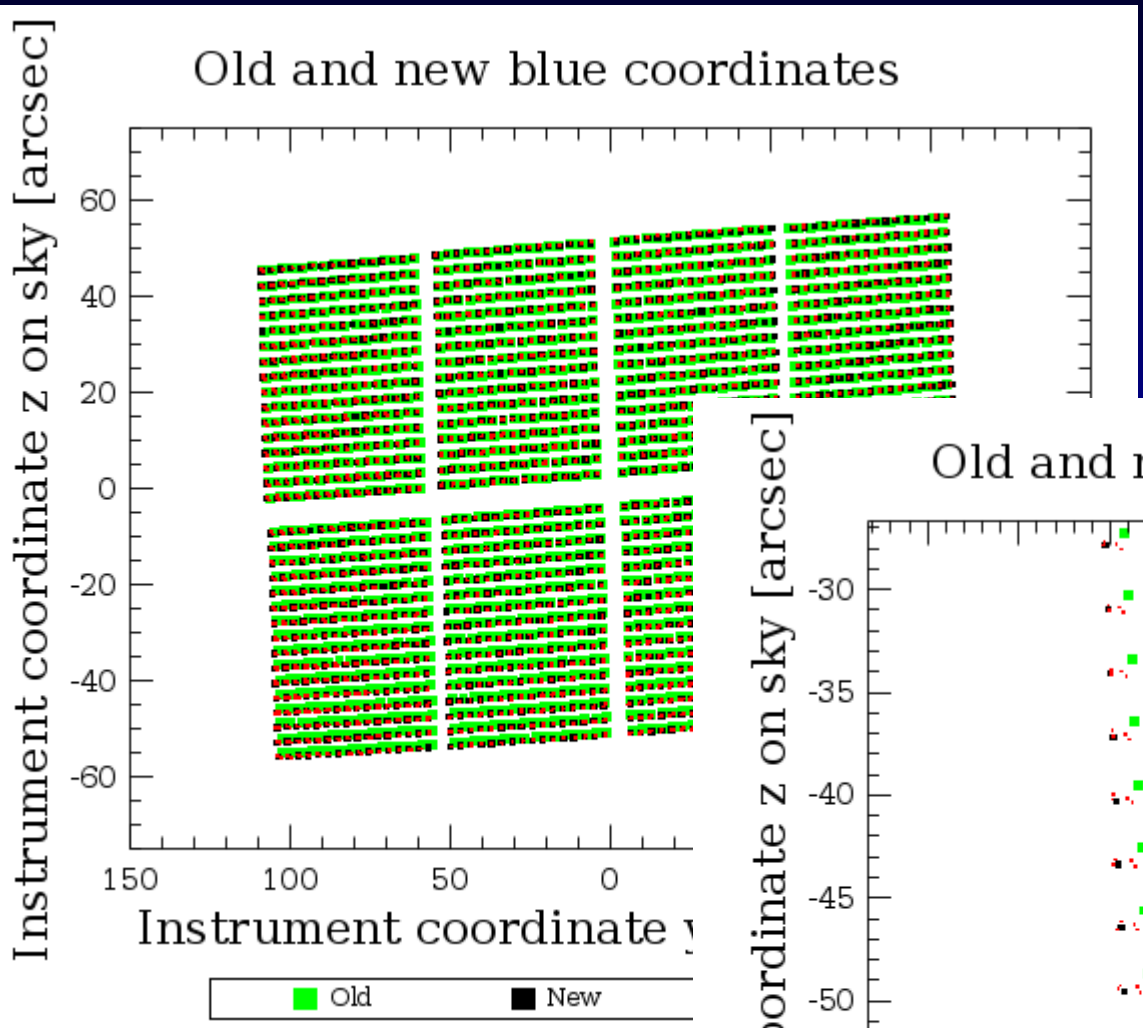
- Current calibration of positions of PACS bolometer pixels on sky is still based on ILT measurements in the lab, using a hole source on an XY stage
- Transfer to sky using optical models of ILT test optics and Herschel telescope, plus global scaling/rotation of pattern as constrained by a detailed raster early in the mission.
- Initially, Herschel pointing too noisy for a reliable full re-derivation.

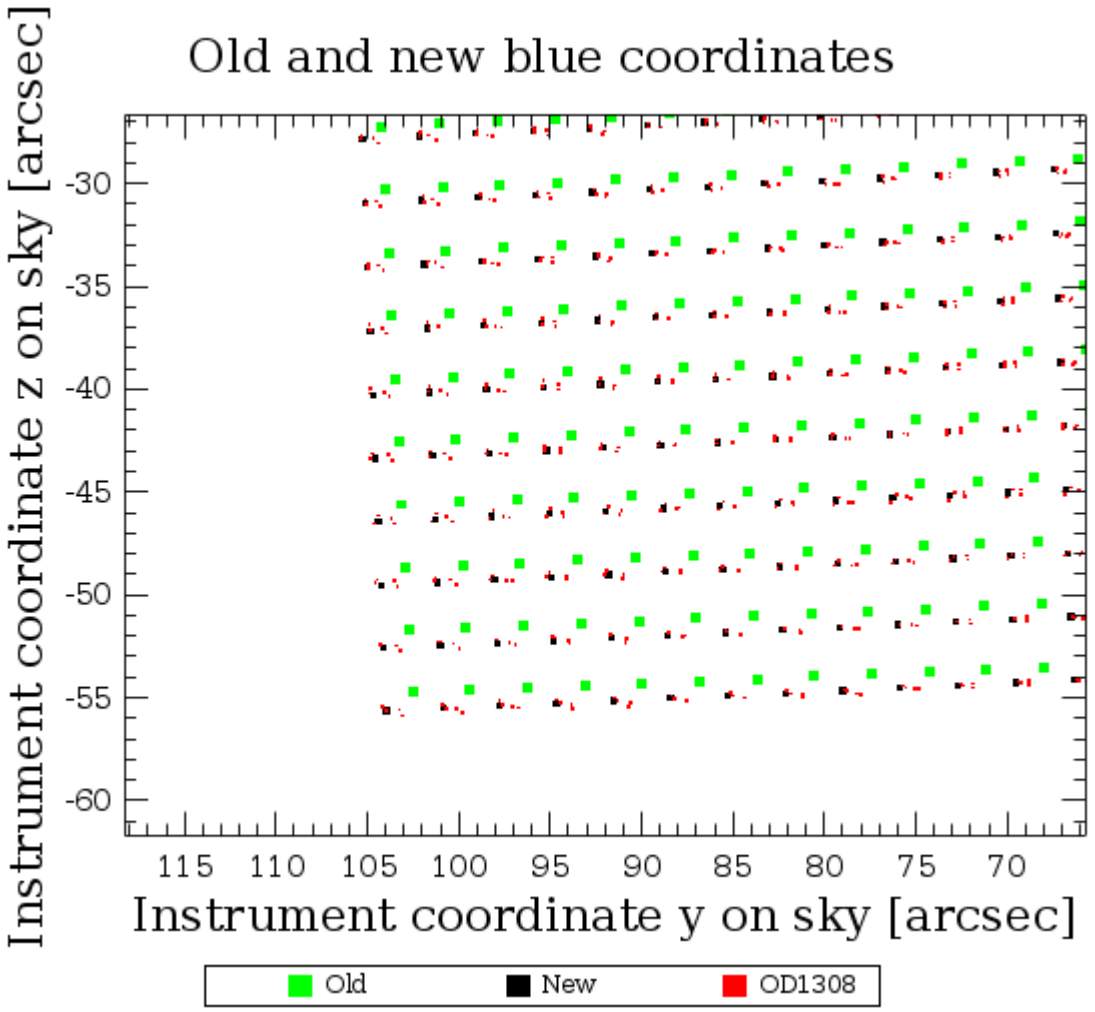
- With new gyro reconstructed pointing, it is now possible to re-derive from scratch, without invoking the ILT data and optical models
- Dedicated measurements taken in OD1308. Residues of measurements vs. a simple matrix location + distortion model < 0.3 arcsec

- Investigation of general applicability ongoing

- Likely impact on PSF width:
  - pretty minor for red
  - Most noticeable in blue.
  - 'Old' pointing masks improvement….

Band	Speed arcsec/sec	FWHM arcsec αTau OD118 normal processing	PA deg	FWHM arcsec αTau OD118 recentered	PA deg	Ratio
Blue	10	5.46×5.78		5.20×5.56		1.045
Blue	20	5.61×6.29		5.41×5.71		1.069
Blue	60	5.92×9.15	60.8	5.70×8.92	61.7	1.032
Green	10	6.67×6.95		6.52×6.75		1.026
Green	20	6.78×7.29		6.64×6.84		1.043
Green	60	7.01×9.89	61.6	6.84×9.64	61.8	1.025
Red	10	10.56×12.06	11.5	10.41×12.00	8.4	1.010
Red	20	10.86×12.18	16.5	10.57×12.05	9.7	1.010
Red	60	11.33×13.35	39.2	11.35×13.32	40.9	1.000


Old and new blue coordinates
Instrument coordinate z on sky [arcsec]
60
40
20
0
-20
-40
-60
150
100
50
0
Instrument coordinate y
Old
New


Old and new blue coordinates
Instrument coordinate z on sky [arcsec]
-30
-35
-40
-45
-50
-55
-60
115
110
105
100
95
90
85
80
75
70
Instrument coordinate y on sky [arcsec]
Old
New
OD1308

The End

- Berta et al. 2010 A&A 518, L30 (short discussion of PEP reduction)
- Lutz et al. 2011 A&A 532, A90 (longer discussion of PEP reduction)
- Popesso et al. 2012 arXiv 1211.4257 (HPF effects, noise scaling)
- ICC/HSC documentation on (e.g.) PACS PSF
- http://www.mpe.mpg.de/ir/Research/PEP/index.php